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Improved proper motion determinations for 15 open clusters based on the UCAC4 catalog

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Abstract The proper motions of 15 nearby ($d < 1$ kpc) open clusters were recalculated using data from the UCAC4 catalog. Only evolved or main sequence stars inside a certain radius from the center of the cluster were used. The results differ significantly from the ones presented by Dias et al. (2014). This could be explained by the different approach to taking the field star contamination into account. The present work aims to emphasize the importance of applying photometric criteria for the calculation of OC proper motions.

1 INTRODUCTION

Open clusters (OCs) are fundamental building blocks of spiral and irregular galaxies. Studies of galactic OCs have produced a vast amount of important scientific results in areas such as stellar evolution and star formation (Castellani et al. 2002; Phelps & Janes 1993). Furthermore, galactic OCs are crucial for the understanding of the structure and dynamics of the Milky Way. Open clusters and OB associations have been used to explore local structures (de Zeeuw et al. 1999; Torra et al. 2000) as well as the large-scale structure of the galaxy (Bobylev & Bajkova 2014; Zhu 2008). They also help tracing the chemical composition throughout the galactic thin disk (Magrini & Randich 2015).

Proper motion is a key parameter of open clusters. Proper motions, distances and radial velocities are used to derive galactocentric velocities of OCs. The latter are of fundamental significance in galactic dynamics studies, e.g. determination of OC orbits (Wu et al. 2009) and rotation of the Galaxy (Dias & Lépine 2005; Zhu 2007). Another important implication of OC proper motions is the calculation of membership probabilities for individual stars (Sanders 1971; Cabrera-Cano & Alfaro 1985). It has been shown that cluster parameters based on photometric membership probabilities are consistent with those based on proper motion membership probabilities, see e.g. Wu et al. (2007).

The early history of open cluster proper motion determinations has been outlined by Vasilevskis (1962). Up until the end of the 20th century proper motions of OCs were derived mainly on a case-by-case basis. The first large catalog was compiled by Glushkova et al. (1997), for 181 clusters with $\log(\text{age}) < 8.3$. Large OC proper motion catalogs were later released by Baumgardt et al. (2000) and Dias et al. (2001, 2002) using Hipparcos and Tycho-2 data respectively. The results, obtained by Loktin

Table 1 Open clusters studied in the current work. The basic parameters are retrieved from the WEBDA database.

cluster	alt. name	$\alpha(J2000)$	$\delta(J2000)$	l	b	dist. [pc]	(m-M)	E(B-V)	log(age)
NGC 1039	M34	02:42:05	+42:45:42	143.658	-15.613	499	8.71	0.07	8.25
NGC 1647	—	04:45:55	+19:06:54	180.337	-16.772	540	9.81	0.37	8.16
NGC 1662	—	04:48:27	+10:56:12	187.695	-21.114	437	9.14	0.30	8.63
NGC 2281	—	06:48:17	+41:04:42	174.901	16.881	558	8.93	0.06	8.55
NGC 2358	—	07:16:55	-17:08:59	231.05	-2.30	630	9.06	0.02	8.72
NGC 2422	M47	07:36:35	-14:29:00	230.958	3.130	490	8.67	0.07	7.86
NGC 2516	—	07:58:04	-60:45:12	273.816	-15.856	409	8.37	0.10	8.05
NGC 2547	—	08:10:09	-49:12:54	264.465	-8.597	455	8.42	0.04	7.56
NGC 3532	—	11:05:39	-58:45:12	289.571	1.347	486	8.55	0.04	8.49
NGC 6124	—	16:25:20	-40:39:12	340.741	6.016	512	10.87	0.75	8.15
NGC 6281	—	17:04:41	-37:59:06	347.731	1.972	479	8.86	0.15	8.50
NGC 6405	M6	17:40:20	-32:15:12	356.580	-0.777	487	8.88	0.14	7.97
NGC 6494	M23	17:57:04	-18:59:06	9.894	2.834	628	10.09	0.36	8.48
NGC 7092	M39	21:31:48	+48:26:00	92.403	-2.242	326	7.61	0.01	8.45
IC 4725	M25	18:31:47	-19:07:00	13.702	-4.434	620	10.44	0.48	7.97

& Beshenov (2003) were also based on the Tycho-2 catalog, and are currently the ones cited in the SIMBAD database.

The UCAC4 catalog (Zacharias et al. 2013) contains proper motion data for more than 105 million objects (complete to $R=16$ mag). It compiles astrometric data from over 140 catalogs, including Hipparcos and Tycho-2, for the derivation of mean positions and proper motions. The astrometry is complemented by optical and NIR photometry from APASS and 2MASS. Dias et al. (2014) have used UCAC4 to obtain proper motions for 1805 galactic OCs. We have recalculated the proper motions of 15 close ($d < 1$ kpc from the Sun) open clusters via a different method and obtained results, significantly different from the ones by Dias et al. (2014).

2 OBJECT SELECTION AND METHOD

The open clusters for this work were selected from the WEBDA list¹ of close OCs ($d < 1$ kpc). Clusters closer than 300 pc were not included as there should be systematic differences between the proper motions of their members, depending on location. We chose only prominent OCs, whose color-magnitude diagrams (CMDs) present typical features for open clusters (main sequence, turnoff point). The selected clusters are presented in Table 1.

Stars in the vicinity of each cluster were extracted by searching the UCAC4 catalog inside a given radius from the cluster center. We used the same coordinates and radii of search as Dias et al. (2014). A 2MASS ($J - K$) vs K diagram was built for each cluster. Out of all the N_0 stars, N_1 were selected as very probable cluster members based on their location on the CMD. Only stars lying on the main sequence (MS) or evolved ones, i.e. to the right from the MS and forming a feature along an isochrone, were included in the N_1 subselections (Fig. 1). Data selection was carried out using Virtual Observatory tools (Aladin² and TOPCAT³).

Outlying points in the N_1 subselections were removed using median absolute deviation (MAD), defined as:

$$MAD(x) = \text{median}_i(|x_i - \text{median}_j(x_j)|)$$

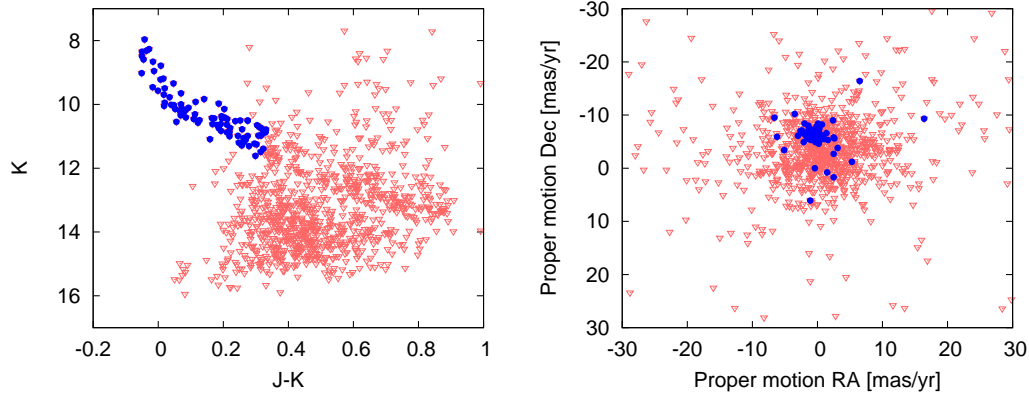
$$MAD(\mu) = \sqrt{(MAD(\mu_{\alpha \cos \delta}))^2 + (MAD(\mu_{\delta}))^2} \quad (1)$$

¹ See http://www.univie.ac.at/webda/dist_list.html

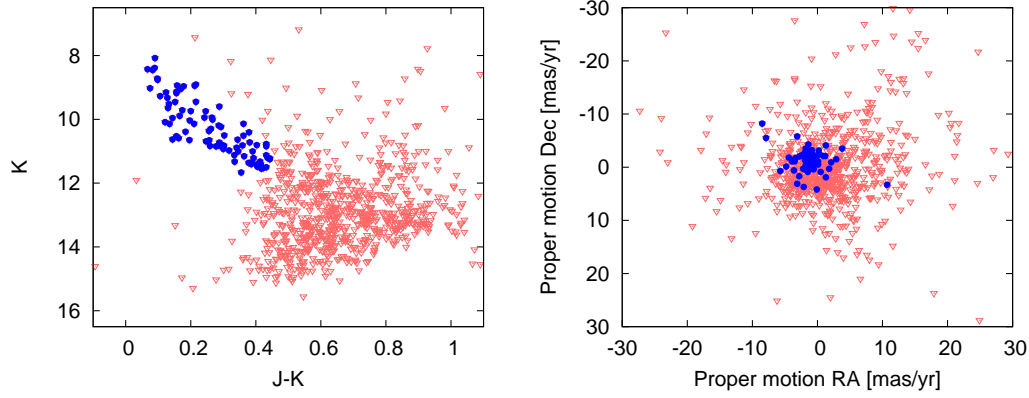
² See <http://aladin.u-strasbg.fr/>

³ See <http://www.star.bris.ac.uk/~mbt/topcat/>

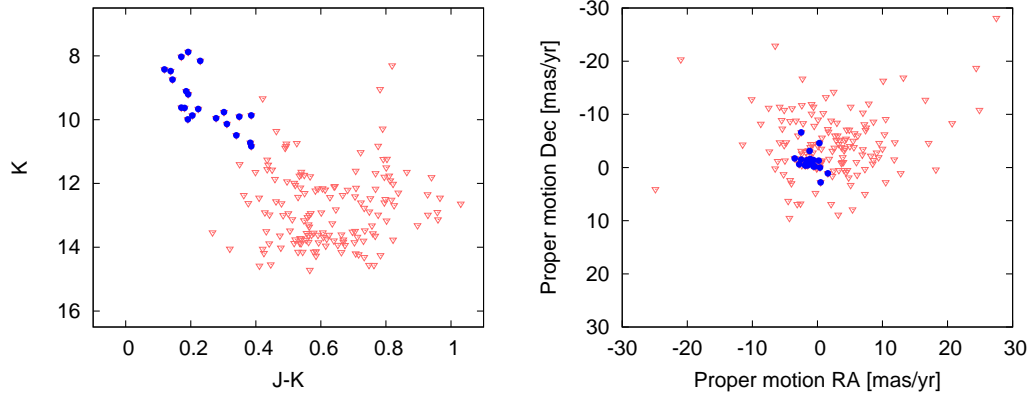
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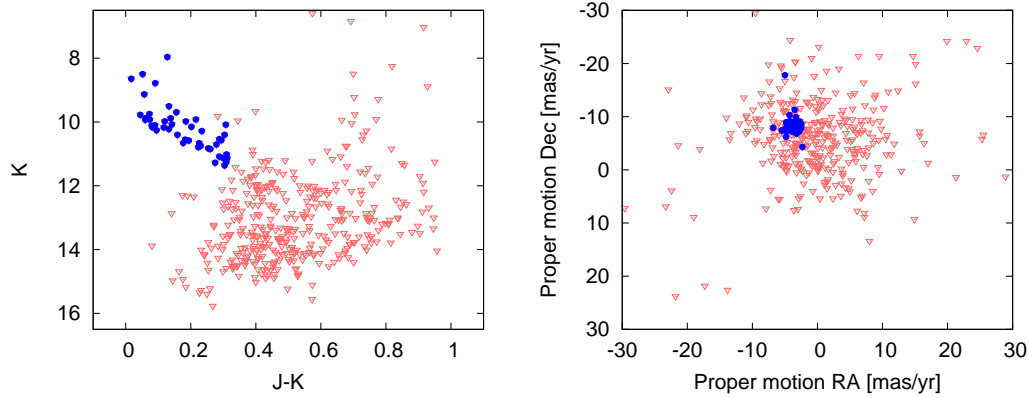
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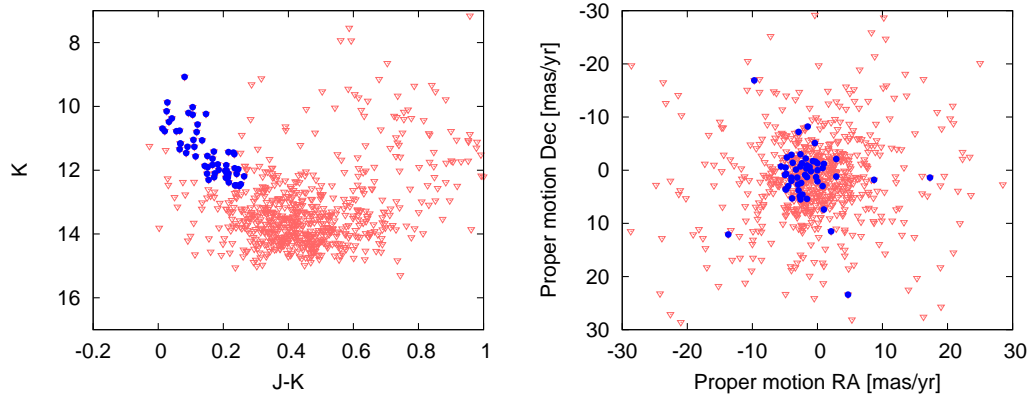
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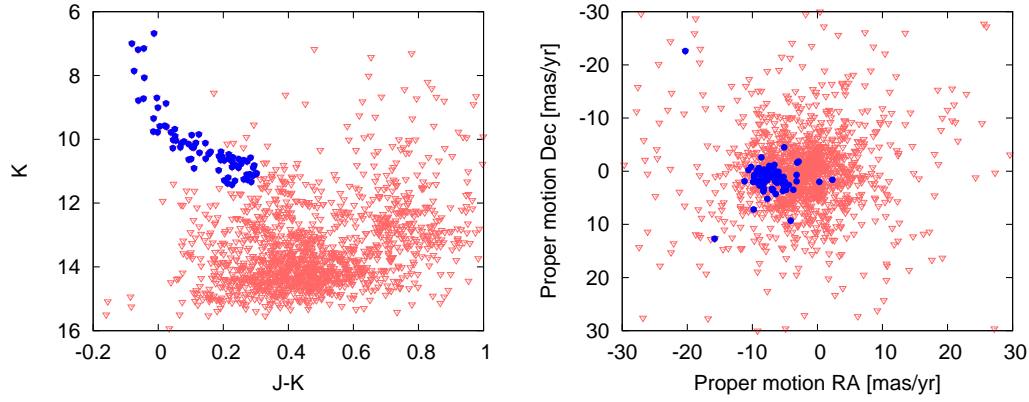
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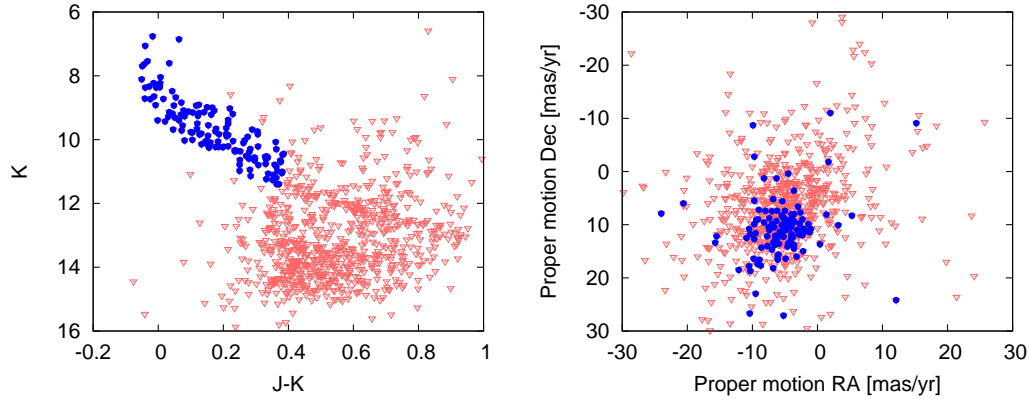
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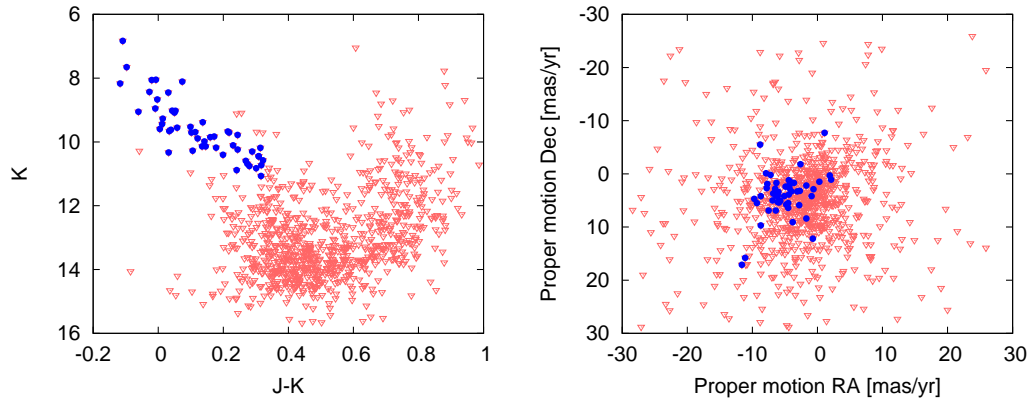
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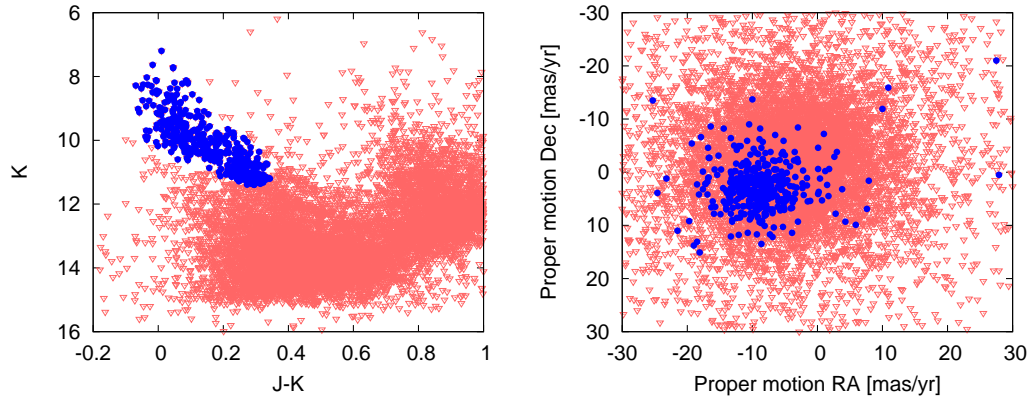
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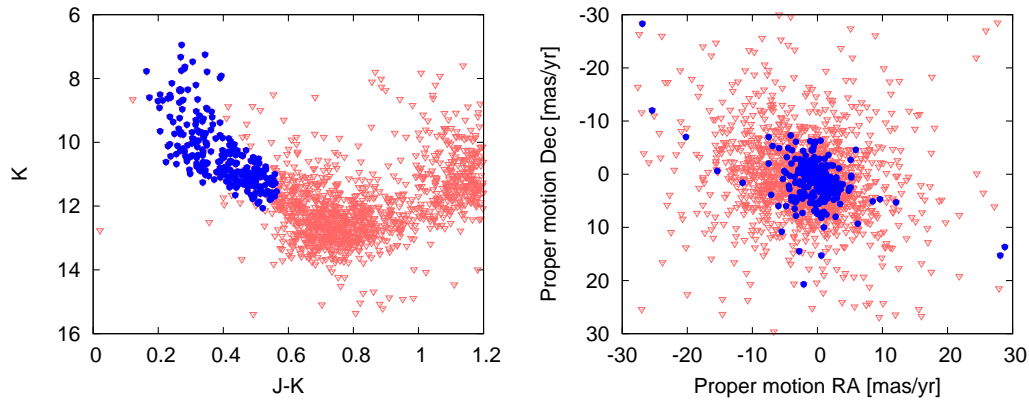
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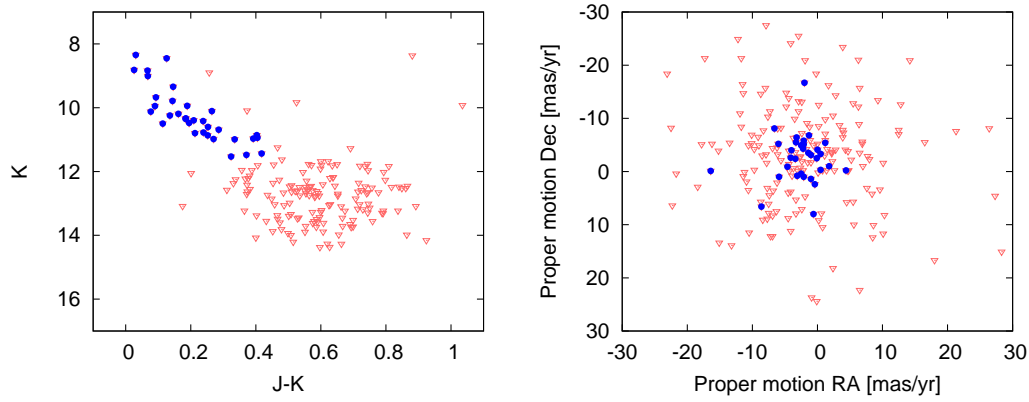
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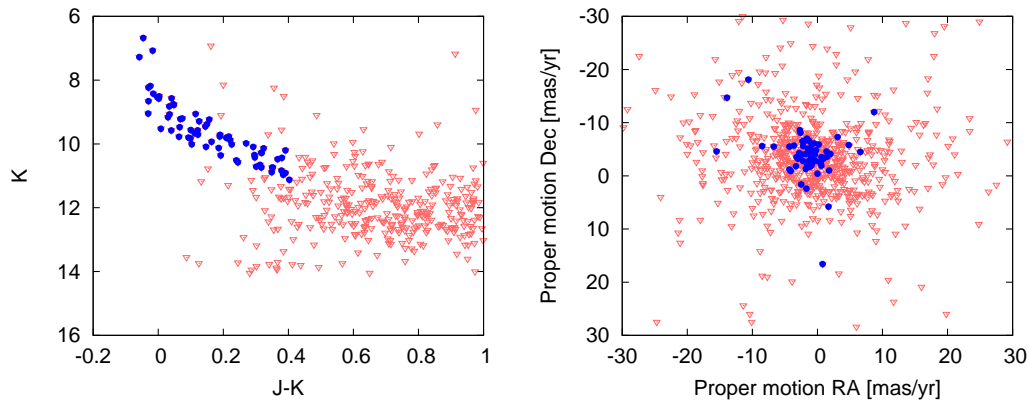
NGC 6124



NGC 6281



NGC 6405



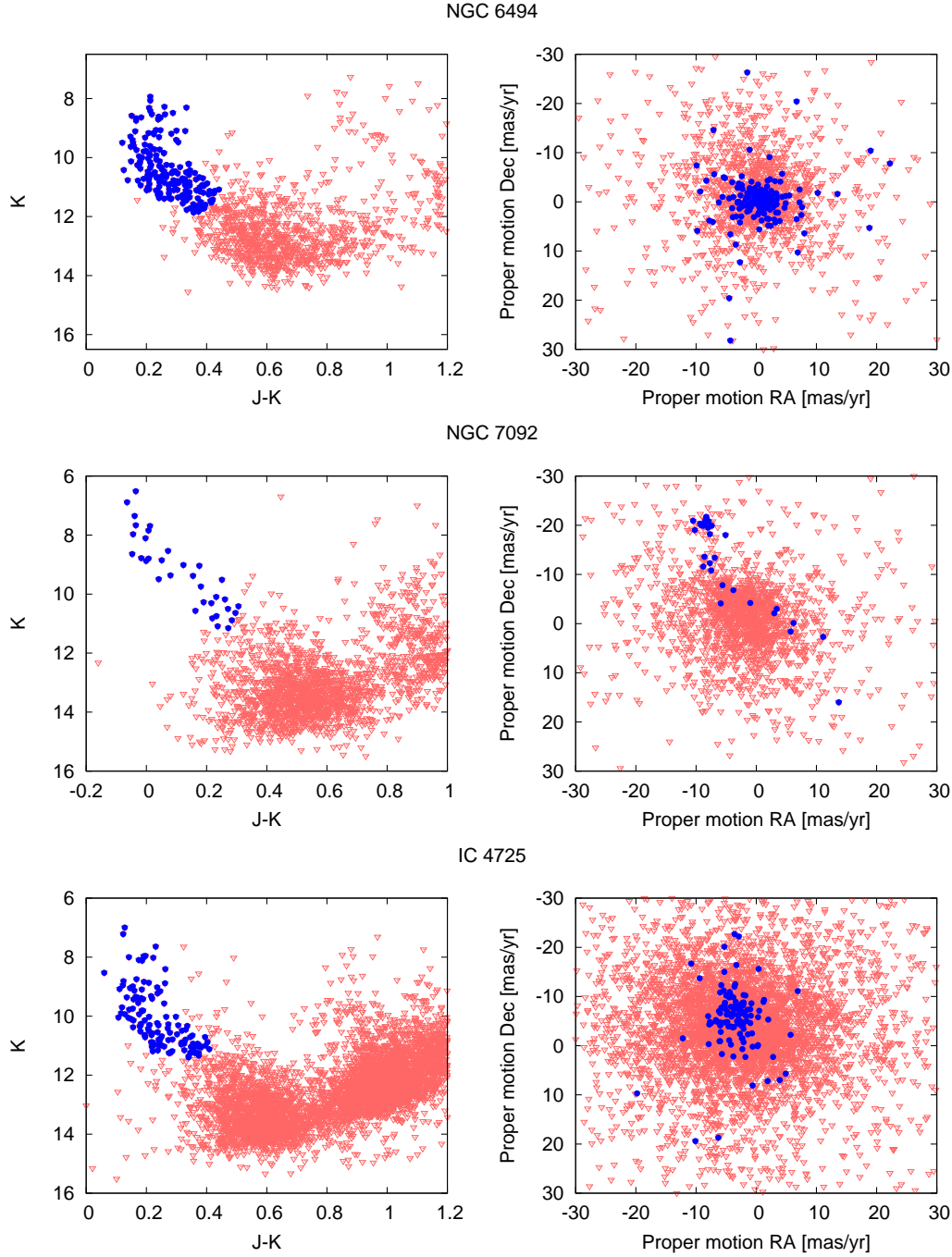


Fig. 1 *left*: NIR color-magnitude diagrams of all clusters. All stars inside the search radii are plotted with red triangles. Filled blue dots represent highly probable cluster members (the N_1 subselections), used to calculate the OC proper motions after the omission of outlying points. *right*: All sources plotted in a $\mu_\alpha \cos \delta$ vs μ_δ plane. Cluster members appear grouped together.

Table 2 Proper motions calculated for 15 open clusters. The last column contains the number of stars used by [Dias et al. \(2014\)](#).

cluster name	r_s [arcmin]	N_0	N_1	$MAD(\mu)$ [mas/yr]	N_2	$\mu_\alpha \cos \delta$ [mas/yr]	σ_α [mas/yr]	μ_δ [mas/yr]	σ_δ [mas/yr]	N_D
NGC 1039	18.5	1022	86	0.92	72	-0.56	1.03	-6.26	0.82	783
NGC 1647	21.0	848	87	1.14	78	-1.13	1.35	-1.27	1.24	656
NGC 1662	11.0	173	21	0.99	19	-1.10	1.24	-0.66	1.21	151
NGC 2281	13.5	439	46	0.92	43	-3.92	0.91	-8.21	0.92	330
NGC 2358	11.0	750	55	2.83	49	-1.85	2.56	0.49	3.10	618
NGC 2422	13.5	1487	78	1.64	73	-7.29	1.87	1.38	1.79	1293
NGC 2516	16.0	941	134	2.84	117	-5.48	3.13	11.14	3.36	737
NGC 2547	13.5	960	51	2.55	48	-4.88	2.80	3.71	2.96	644
NGC 3532	26.0	11974	409	3.40	386	-8.90	3.91	2.97	3.80	8705
NGC 6124	20.5	1838	263	2.72	243	-0.18	2.49	1.19	3.16	1633
NGC 6281	5.0	280	33	2.83	30	-1.92	2.40	-2.51	3.40	207
NGC 6405	11.0	930	67	2.05	61	-1.11	2.33	-3.87	2.12	737
NGC 6494	15.5	1640	185	2.36	162	0.49	2.80	-0.27	2.37	1342
NGC 7092	15.5	2019	34	2.77	25	-8.20	1.18	-18.14	3.97	1464
IC 4725	15.5	5812	124	2.84	111	-3.46	2.55	-6.01	3.76	4458

The value of $MAD(\mu)$ was calculated for each cluster. Sources with proper motion differing by more than $4MAD(\mu)$ from the median proper motion were considered outliers and excluded from the sample, thus producing even narrower subselections consisting of N_2 stars. The proper motions of the clusters were finally calculated by averaging the data in the N_2 subselections.

3 RESULTS

Our results are presented in Table 2. The standard deviations of the proper motions in the N_2 subselections are in the range of 0.8 mas/yr–4 mas/yr, which is comparable to the errors given by [Dias et al. \(2014\)](#). However, the results differ significantly from theirs ($|\Delta\mu| > 2$ mas/yr for 9 of the 15 clusters). Very large deviations are observed for NGC 7092, NGC 3532 and NGC 2422. Higher deviations from [Dias et al. \(2014\)](#) are generally observed at higher absolute proper motion values (Fig. 2).

We suggest that [Dias et al. \(2014\)](#) may have used a large number of background stars, which could have contaminated their selections. We attempted to estimate the percentage of those background stars. For each cluster we examined 4 nearby fields, centered 40' away (60' away in the case of the larger NGC 3532), and with radius r_s , equal to the search radius for the cluster (Table 2). The median number N_F of UCAC4 sources in these 4 fields was then calculated. The portion of field stars should be roughly $f = N_F/N_0$. For all clusters $f > 67\%$. The portion of field stars among those used by [Dias et al. \(2014\)](#) would be approximately $f_D = 1 - (1 - f)N_0/N_D$. The minimum and median values of f_D are 57% and 75% respectively. Although this is just a rough estimate, it shows that a considerable portion of stars used by [Dias et al. \(2014\)](#) are not physical members of the respective clusters.

[Loktin & Beshenov \(2003\)](#) have also applied photometric criteria for their selections. Our agreement with the latter is slightly better in general (median $|\Delta\mu|$ of 1.6 mas/yr) and much better in the case of NGC 7092 ($|\Delta\mu| = 1.52$ mas/yr and 17.08 mas/yr when comparing the data in Table 2 to [Loktin & Beshenov \(2003\)](#) and [Dias et al. \(2014\)](#) respectively). The proper motion diagram for NGC 7092 (Fig. 1) contains a considerable number of outlying points. The reason is that NGC 7092 is a very close cluster, located near the galactic plane (Table 1). Most of the outliers are not in the N_2 subselection and do not affect the result as they lie farther than $4MAD(\mu)$ from the median value.

4 SUMMARY

Proper motions are important parameters of open clusters, which help us improve our understanding of galactic dynamics. We built NIR color-magnitude diagrams of 15 open clusters and we used them to select stars that are very probable members. After excluding the ones with an uncommon proper

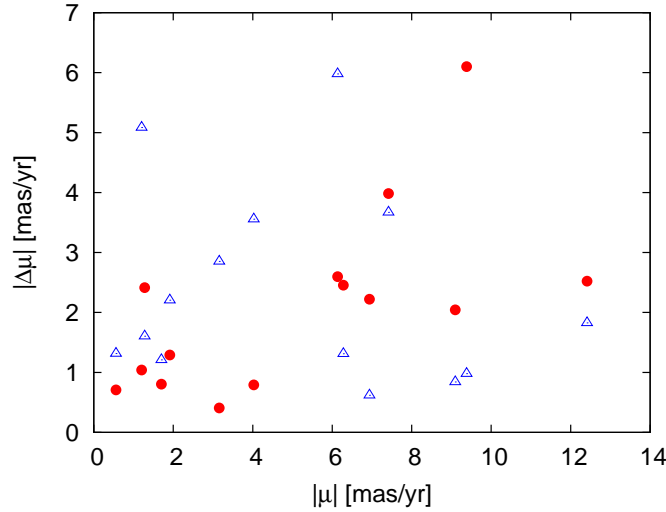


Fig. 2 Comparison of the calculated proper motions with the values by [Dias et al. \(2014\)](#) (*red circles*) and [Loktin & Beshenov \(2003\)](#) (*blue triangles*). The x-axis represents absolute proper motion values, calculated in this work, while the y-axis represents absolute values of vector differences to the previous estimates. The [Dias et al. \(2014\)](#) data point for NGC 7092 lies outside the plot, at $(|\mu|, |\Delta\mu|) = (18.18, 17.08)$.

motion, we used those subselections to calculate the proper motions of the clusters. Our results suggest that [Dias et al. \(2014\)](#) may have used selections, contaminated by background stars. Our work shows the advantage of utilizing CMDs for the calculation of open cluster proper motions.

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